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**Richmond, Virginia**

**To:** **Rick Solana** **Date:** **June 4, 1999**

**From:** **Jennifer Amador** Jennif Amador

**Subject:** **Literature review on iron aluminide and medical devices**

I searched the MEDLINE and HealthStar databases and I could find no references to iron aluminide. As an aside, the Oak Ridge National Laboratories website (www.ornl.gov) does indicate its use in automobile components and coal gasification filters.

Another MEDLINE search was done to try to locate current problems of medical devices that may be solved by the use of iron aluminide. Using the search strategy
(corrosion or allergies or metal release) and (hip replacement? or orthopedic surgery or orthodontics) located an article by FJ Gil entitled "Shape memory alloys for medical applications." *(see Attachment 1).* Using the Related Articles command, I located a total of 103 articles on shape memory alloys and their use in medical devices. Two of these articles were biographies and eliminated. The remaining citations are found on Attachment 1.

I also searched the Library's catalog and found several books on the FDA's approval process for medical devices. These have been set aside at the circulation desk.

DOC CODE:

**ATTACHMENT 1**
**Shape memory or superelasticity and medical applications**

Proc Inst Mech Eng [H] 1998;212(6):473-88
**Shape memory alloys for medical applications.**
Gil FJ, Planell JA
Departament de Ciencia dels Materials i Enginyeria Metal-lurgica, Escola Tecnica Superior d'Enginyers de Barcelona, Universitat Politecnica deCatalunya, Spain.

The shape memory alloys exhibit a number of remarkable properties, which open new possibilities in engineering and more specifically in biomedical engineering. The most important alloy used in biomedical applications is NiTi. This alloy combines the characteristics of the shape memory effect and superelasticity with excellent corrosion resistance, wear characteristics, mechanical properties and a good biocompatibility. These properties make it an ideal biological engineering material, especially in orthopaedic surgery and orthodontics. In this work the basis of the memory effect lies in the fact that the materials exhibiting such a property undergo a thermoelastic martensitic transformation. In order to understand even the most elementary engineering aspects of the shape memory effect it is necessary to review some basic principles of the formation and the characteristics of the martensitic phase. The different properties of shape memory, superelasticity, two-way shape memory, rubber-like behaviour and a high damping capacity are reviewed. Some applications proposed in recent years are described and classified according to different medical fields.

Biomed Mater Eng 1996;6(4):267-89
**On the nature of the biocompatibility and on medical applications of NiTi shape memory and superelastic alloys.**
Shabalovskaya SA
Ames Laboratory, Department of Energy, Iowa 50011, USA. shabalov@ameslab.gov

Nitinol based shape memory alloys were introduced to Medicine in the late seventies. They possess a unique combination of properties including shape memory, superelasticity, great workability in the martensitic state, resistance to fatigue and corrosion. Despite these exceptional physical, chemical and mechanical properties the worldwide medical application has been hindered for a long time because of the lack of knowledge on the nature of the biocompatibility of these enriched by nickel alloys. A review of biocompatibility with an emphasis on the most recent studies, combined with the results of X-ray surface investigations, allows us to draw conclusions on the origin of the good biological response observed in vivo. The tendency of Nitinol surfaces to be covered with TiO2 oxides with only a minor amount of nickel under normal conditions is considered to be responsible for these positive results. A certain toxicity, usually observed in in vitro studies, may result from the much higher in vitro Ni concentrations which are probably not possible to achieve in vivo. The essentiality of Ni as a trace element may also contribute to the Nitinol biocompatibility with the human body tissues. Examples of successful medical applications of Nitinol utilizing shape memory and superelasticity are presented.

Biomed Mater Eng 1998;8(2):55-60

**Shape memory and superelastic alloys: the new medical materials with growing demand.**

Van Moorleghem W, Chandrasekaran M, Reynaerts D, Peirs J, Van Brussel H
Advanced Materials and Technologies, Herk-de-Stad, Belgium.
amt.shapememory@tornado.be

Shape memory and superelasticity are novel properties not exhibited by common materials. In recent years, these properties and the alloys exhibiting them have found widespread use as new medical materials, in devices such as diagnostic and therapeutic catheters of different kinds, stents, needle wire localisers, orthodontic arch wires, implantable drug delivery system etc. The reasons for this trend and the future potential of these materials in medical applications will be explained in this presentation.

J Endourol 1997 Dec;11(6):383-9

**Characteristics of metals used in implants.**

Gotman I
Department of Materials Engineering, Technion, Haifa, Israel.

The performance of any material in the human body is controlled by two sets of characteristics: biofunctionality and biocompatibility. With the wide range of materials available in the mid-1990s, it is relatively easy to satisfy the requirements for mechanical and physical functionality of implantable devices. Therefore, the selection of materials for medical applications is usually based on considerations of biocompatibility. When metals and alloys are considered, the susceptibility of the material to corrosion and the effect the corrosion has on the tissue are the central aspects of biocompatibility. Corrosion resistance of the currently used 316L stainless steel, cobalt-chromium, and titanium-based implant alloys relies on their passivation by a thin surface layer of oxide. Stainless steel is the least corrosion resistant, and it is used for temporary implants only. The titanium and Co-Cr alloys do not corrode in the body; however, metal ions slowly diffuse through the oxide layer and accumulate in the tissue. When a metal implant is placed in the human body, it becomes surrounded by a layer of fibrous tissue of a thickness that is proportional to the amount and toxicity of the dissolution products and to the amount of motion between the implant and the adjacent tissues. Pure titanium may elicit a minimal fibrous encapsulation under some conditions, whereas the proliferation of a fibrous layer as much as 2 mm thick is encountered with the use of stainless steel implants. Superior fracture and fatigue resistance have made metals the materials of choice for traditional load-bearing applications. In this review, the functionality of currently used metals and alloys is discussed with respect to stenting applications. In addition, the "shape memory" and "pseudo-elasticity" properties of Nitinol-an alloy that is being considered for the manufacturing of urologic stents-are described.

Biomed Mater Eng 1996;6(4):291-8

**Review of shape memory alloys medical applications in Russia.**

Brailovski V, Trochu F
Ecole Polytechnique of Montreal, Department of Mechanical Engineering, Quebec, Canada.

In the last twenty-five years a large variety of research has been carried out in Russia using Shape Memory Alloys (SMA), particularly nearly equiatomic NiTi alloys, for medical applications. In this field of activity, Russian research centers have been quite successful in treating different kinds of diseases, from bone fractures to dental implants. This review is intended to give a panorama of SMA medical applications in Russia in order to illustrate the remarkable possibilities offered by SMA materials in the medical field.

Biomed Mater Eng 1996;6(4):233-40

**Studies and applications of NiTi shape memory alloys in the medical field in China.**

Dai K, Chu Y
Ninth People's Hospital, Shanghai Second Medical University, PRC.

The biomedical study of NiTi shape memory alloys has been undertaken in China since 1978. A series of stimulating corrosion tests, histological observations, toxicity tests, carcinogenicity tests, trace nickel elements analysis and a number of clinical trials have been conducted. The results showed that the NiTi shape memory alloy is a good biomaterial with good biocompatibility and no obvious local tissue reaction, carcinogenesis or erosion of implants were found experimentally or clinically. In 1981, on the basis of fundamental studies, a shape memory staple was used for the first time inside the human body. Subsequently, various shape memory devices were designed and applied clinically for internal fixation of fractures, spine surgery, endoprostheses, gynaecological and craniofacial surgery. Since 1990, a series of internal stents have been developed for the management of biliary, tracheal and esophageal strictures and urethrostenosis as well as vascular obturator for tumour management. Several thousand cases have been treated and had a 1-10 year follow-up and good clinical results with a rather low complication rate were obtained.

Biomed Mater Eng 1996;6(4):299-305

**Innovative materials: the NiTi alloys in orthodontics.**

Airoldi G, Riva G

Since ten years the NiTi alloys have gained an ever increasing place in orthodontic practice: that is due to their peculiar mechanical properties ascribed to a martensitic thermoelastic transformation which can be thermally or, in a proper temperature range, stress-induced. In the last case, when martensite is stress-induced at body temperature, the stress-strain behaviour is pseudoelastic with large deformations gained or recovered at constant stress, respectively in direct/reverse transformation: this behaviour exploited in orthodontics allowed to overcome the drawbacks intrinsic to the use of conventional alloys as stainless steel or Co-Mo alloys, where small displacements can be achieved at decreasing loads. From the phase state diagram of NiTi alloys it appears that at body temperature they are stable, but out of equilibrium: thermal treatments at intermediate temperatures can therefore modify the equilibrium state and as a consequence the transformation temperatures respect to body temperature. That allows to modify the recovery stress level according to the requirements of practice and thus disclosing newroads: the capability to foresee NiTi archwires pre-programmed in different sections, with a personalized scheme. Attention has not currently been paid to the modifications in the recovery stress induced by a temperature change inside the oral cavity. Recent results have shown that the thermal changes in the oral cavity induced by cold/hot liquid intake can considerably modify the stress level to which the dentition is exposed: though confined to the time extent connected with drinking, similar effects can be expected also for meals intake and should be taken into account for a correct procedure.

TBiomed Mater Eng 1997;7(4):253-63

**New titanium alloys for biomaterials: a study of mechanical and corrosion properties and cytotoxicity.**

Kim TI, Han JH, Lee IS, Lee KH, Shin MC, Choi BB

Department of Prosthodontics, School of Dentistry, Kyung Hee University, Seoul,Korea.

Three new titanium alloys with Zr, Nb, Ta, Pd and In as alloying elements were developed and compared with currently used implant metals, namely, pure Ti andTi-6Al-4V alloy, in terms of mechanical and corrosion properties, and cytotoxicity. New alloys showed comparable mechanical properties with that of the Ti-6Al-4V alloy, but increased corrosion potential, somewhat decreased breakdown potential and increased corrosion rate. There were no significant differences in cell growth on the surface of the various metal specimens, indicating that the cells cannot differentiate between the passivated surfaces of the various Ti metals.

J Biomed Mater Res 1998 Sep 5;41(3):481-8

**In vivo biocompatibility evaluation of nickel-titanium shape memory metal alloy: muscle and perineural tissue responses and encapsule membrane thickness.**

Ryhanen J, Kallioinen M, Tuukkanen J, Junila J, Niemela E, Sandvik P, Serlo W
Department of Surgery, Oulu University Central Hospital, University of Oulu, Finland.

Nickel-titanium shape memory alloy (Nitinol) has properties that could be very useful in surgical applications. Thermal shape memory, superelasticity, and high damping properties make such alloys behave differently compared to other implant metals. There has previously been a lack of sufficient evidence on the biocompatibility of Nitinol. The purpose of this study was to evaluate general soft tissue response and biocompatibility to Nitinol in vivo, and to clarify neural and perineural responses, previously unreported. Seventy-five rats were randomized into three groups. Test specimens were implanted into paravertebral muscle and near the sciatic nerve. A comparison was made between Nitinol, stainless steel, and Ti-6Al-4V. The animals were euthanized at 2, 4, 8, 12, and 26 weeks after implantation. General morphologic and histologic observations were made under light microscopy. Semiautomatic computerized image analysis was used to measure the encapsule membrane thickness around the implants. The muscular tissue response to Nitinol was clearly nontoxic, regardless of the time period. The overall inflammatory response to Nitinol was very similar to that of stainless steel and Ti-6Al-4V alloy. There were no necroses, granulomas, or signs of dystrophic soft tissue clacification. The immune cell response to Nitinol remained low. Only a few foreign-body giant cells were present. The detected neural and perineural responses were also clearly nontoxic and nonirritating with Nitinol. No qualitative differences in histology between the different test materials could be seen. At 8 weeks, the encapsule membrane of Nitinol was thicker than that of stainless steel (mean 62 +/- 25 microns vs. 41 +/- 8 microns). At the end of the study, the encapsule thickness was equal to all the materials tested. We concluded that Nitinol had good in vivo biocompatibility after intramuscular and perineural implantation in rats in the 26-week follow-up. Based on the results of the present study, Nitinol appears to have good potential for clinical use.

Biomaterials 1996 Nov;17(22):2117-26

**In-vitro corrosion and wear of titanium alloys in the biological environment.**

Khan MA, Williams RL, Williams DF
Department of Clinical Engineering, Faculty of Medicine, University of Liverpool, UK.

Cyclic anodic polarization studies were undertaken for several titanium alloys of varying composition and phase structures. All materials were exposed to an accelerated corrosion test using a potentiostat and their electrochemical behaviour was analysed within a potential range of 0 to 5000 mV. The electrolyte used was a phosphate buffered saline (PBS) solution at pH = 5, 7.4 and 9. The polarization curves obtained represented both the passive and active regions of the materials and these curves were used to compare the resistance to pitting corrosion of each material. The sliding-wear of these materials was studied in both non-corrosive and corrosive environments. A simple pin-on-disc type wear apparatus was designed and built to simulate the co-joint action of corrosion and sliding-wear. Using this apparatus, it was also possible to evaluate the effect of wear-accelerated corrosion, which was also evaluated by wearing the surface of the specimens prior to corrosion. It was evident that the mixed phase alpha-beta

alloys (Ti-6Al-4V and Ti-6Al-7Nb) possessed the best combination of both corrosion and wear resistance, although commercially pure titanium and the near-beta (Ti-13Nb-13Zr) and beta (Ti-15Mo) alloys displayed the best corrosion resistant properties.

Crit Rev Biomed Eng 1994;22(3-4):139-251

**Corrosion and other electrochemical aspects of biomaterials.**

Bundy KJ
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Metallic materials are used extensively as orthopedic implants, dental materials, sensing elements of bioelectrodes, and other applications. The electrochemical behavior of these biomaterials is of interest for a variety of reasons. The corrosion resistance of an implant material influences its functional performance and durability and is a primary factor governing biocompatibility. Among the aspects affecting biocompatibility are the amounts and forms of released corrosion products and their disposition in the body after release. Electrochemical principles are very useful for understanding the factors affecting corrosion resistance and also form the foundation for many biosensors that measure the concentration of various chemical entities (including released corrosion products and naturally occurring substances). Many electrochemical measurement techniques have been used to study biomaterials for years (e.g., polarization curve measurement), while others (such as polarography and AC impedance methods) have been applied more recently. This work focuses on four main topics. The first is the nature of the body's environment as it affects in vivo electrochemical phenomena, that is, the chemical, mechanical, biological, and bioelectrical phenomena that affect the behavior and performance of biomaterials. The second deals with methodology--the techniques used for corrosion measurement and concentration determination, the appropriate environment (laboratory, cell culture, in vivo,etc.), and experimental problems encountered. The third topic treated is the knowledge accumulated regarding the performance of implant alloys in various applications, for example, the forms of corrosion to which they are susceptible, etc. Finally, improvements that may come about in the future regarding both materials and testing methodology are considered.

J Biomed Mater Res 1998 Winter;43(4):433-40

**Effect of modification of oxide layer on NiTi stent corrosion resistance.**

Trepanier C, Tabrizian M, Yahia LH, Bilodeau L, Piron DL
GRBB, Biomedical Engineering Institute, Ecole Polytechnique de Montreal, Quebec, Canada.

Because of its good radiopacity, superelasticity, and shape memory properties, nickel-titanium (NiTi) is a potential material for fabrication of stents because these properties can facilitate their implantation and precise positioning. However, in vitro studies of NiTi alloys report the dependence of alloy biocompatibility and corrosion behavior on surface conditions. Surface oxidation seems to be very promising for improving the corrosion resistance and biocompatibility of NiTi. In this work, we studied the effect on corrosion resistance and surface characteristics of electropolishing, heat treatment, and nitric acid passivation of NiTi stents. Characterization techniques such as potentiodynamic polarization tests, scanning electron microscopy, Auger electron spectroscopy, and X-ray photoelectron spectroscopy were used to relatecorrosion behavior to surface

characteristics and surface treatments. Resultsshow that all of these surface treatments improve the corrosion resistance of the alloy. This improvement is attributed to the plastically deformed native oxide layer removal and replacement by a newly grown, more uniform one. The uniformity of the oxide layer, rather than its thickness and composition, seems to be the predominant factor to explain the corrosion resistance improvement.

Biomaterials 1996 Oct;17(20):2003-8
**Corrosion resistance tests on NiTi shape memory alloy.**
Rondelli G
CNR-ITM, Milano, Italy.

The corrosion performances of NiTi shape memory alloys (SMA) in human body simulating fluids were evaluated in comparison with other implant materials. As for the passivity current in potentiostatic conditions, taken as an index of ion release, the values are about three times higher for NiTi than for Ti6Al4V and austenitic stainless steels. Regarding the localized corrosion, while plain potentiodynamic scans indicated for NiTi alloy good resistance to pitting attack similar to Ti6Al4V, tests in which the passive film is abruptly damaged (i.e. potentiostatic scratch test and modified ASTM F746) pointed out that the characteristics of the passive film formed on NiTi alloy (whose strength can be related to the alloy's biocompatibility) are not as good as those on Ti6Al4V but are comparable or inferior to those on austenitic stainless steels.

Biomed Mater Eng 1996;6(4):255-66
**The utility of superelasticity in medicine.**
Duerig TW, Pelton AR, Stockel D
Nitinol Devices & Components, Inc., Fremont, CA 94539, USA.

Nitinol alloys (Nitinol) exhibit a dramatically enhanced elasticity, known as "superelasticity", which is becoming integral to the design of a variety of new medical products. Elasticity is the most apparent of the advantages afforded by this material, but by no means the only or most important. Also discussed in this paper are features such as biocompatibility, kink resistance, constancy of stress, physiological compatibility, shape memory deployment, dynamic interference and fatigue resistance. Each of these properties is discussed and highlighted through example. Examples presented include stents, filters, retrieval baskets, and surgical tools.

Fortschr Kieferorthop 1990 Dec;51(6):320-6
**[The materials engineering characteristics of orthodontic nickel-titanium wires].**
[Article in German]
Drescher D, Bourauel C, Thier M
Poliklinik fur Kieferorthopadie, Rheinische Friedrich-Wilhelms-Universitat
Bonn.

Since their introduction in 1971 nickel-titanium wires have been widely used in orthodontics. Today, there is a multitude of new NiTi-alloys, whose properties are

described. Beside the memory effect, these alloys have particular elastic properties, which can be characterized by a low modulus of elasticity, excellent springback, and pseudoelasticity (superelasticity). These properties are a consequence of the fact that depending on temperature and mechanical stress NiTi-alloys have two crystalline structures: martensite and austenite. The transition between these two phases, called martensitic transformation, is responsible for the memory effect, where a one way and a two way effect can be distinguished. For orthodontic applications pseudoelasticity is regarded as a highly favourable property. Pseudoelastic behavior is caused by stress induced martensite. Analysing the elastic properties of the available wires two categories can be distinguished: "work hardened martensite" and "pseudoelastic alloy". The biocompatibility of NiTi is sufficient, it can be used as an implant material.

Biomed Mater Eng 1996;6(3):153-7
**A study of load cycling in a NiTi shape memory alloy with pseudoelastic behaviour used in dental prosthetic fixators.**
Sabria J, Cortada M, Giner L, Gil FJ, Fernandez E, Manero JM, Planell JA
Department of Morphological Sciences and Odonto-stomatology, Faculty of Odontology, Universitat de Barcelona, Spain.

NiTi alloy used in dental prosthetic fixators shows pseudoelastic behaviour and exhibits a great potential in dental and orthopaedic applications where constant correcting loads are required. In order to use such materials in dental prosthetic fixators, where the device is cyclically deformed, it is necessary to investigate the effect of the cyclic straining upon the transformation stresses and temperatures of the material. The aim of this work is to study the load cycling of a pseudoelastic NiTi shape memory alloy to be applied in the making of dental prosthetic fixators.

Chung Hua Wai Ko Tsa Chih 1983 Sep;21(9):540-1
**[Application of a NiTi shape-memory alloy in double-cup prosthesis of hip].**
[Article in Chinese]
Dai KR

Biomaterials 1997 Aug;18(16):1115-20
**Cytotoxic, allergic and genotoxic activity of a nickel-titanium alloy.**
Wever DJ, Veldhuizen AG, Sanders MM, Schakenraad JM, van Horn JR
Department of Orthopaedics, University Hospital of Groningen, The Netherlands.

The nearly equiatomic nickel-titanium (NiTi) alloy is known for its shape memory properties. These properties can be put to excellent use in various biomedical applications, such as wires for orthodontic tooth alignment and osteosynthesis staples. The aim of this study was to evaluate the short-term biological safety of the NiTi alloy. We carried out an end-point dilution minimal essential medium (MEM) extract cytotoxicity test, a guinea-pig sensitization test and two genotoxicity tests: the Salmonella reverse mutation test and the chromosomal aberration test. The NiTi alloy showed no cytotoxic, allergic or genotoxic activity, similar to the clinical reference control material AISI 316 LVM stainless steel. This promising biological behaviour was most likely due to a minimal release of ions and in that way a reflection of the good corrosion resistance of the NiTi alloy. Given these very good results, together with the good tissue

compatibility as shown in several implantation studies in the literature, the NiTi alloy can be regarded as a biologically safe implant material with many promising clinical applications.

ASAIO J 1996 Sep-Oct;42(5):M765-8
**Development of a new blood pump using a shape memory alloy actuator.**
Lee DJ, Kim HC, Min BG
Department of Biomedical Engineering, Seoul National University, Korea.

A helical spring shape memory alloy actuator has been investigated to be used in a mechanical circulatory support system. The design procedure to determine shape memory alloy and passive bias spring specifications was established. A model device was designed to provide 2 cm stroke by a 100 cm2 pusher plate against a maximum 200 mm Hg pressure load. The prototype device was also developed to verify the feasibility of the shape memory alloy actuator and to confirm the design procedure. In vitro water bath test results verified the feasibility of the shape memory alloy actuator for use in a mechanical circulatory support system.

Nippon Jibiinkoka Gakkai Kaiho 1984 Apr;87(4):461-7
**[Application of Ti-Ni shape memory alloys to the otorhinolaryngological field].**
[Article in Japanese]
Fujioka M, Miwa Y, Hiraide F

Shigaku 1985 Oct;73(4):883-911
**[The dental application of a Au-Cu-Zn system memory-shape alloy--comparison of the physical and chemical properties with dental alloys].**
[Article in Japanese]
Suzuki T, Yoshida T, Miyasaka T

Stomatol Mediterr 1990 Sep;10(3):221-7
**[Shape memory alloys for orthodontic use studied with electron beams].**
[Article in Italian]
Rapisarda E, Torrisi L
Universita degli Studi di Catania.

Shape memory alloys, which have the ability to be deformed into a temporary shape and then returned to its original shape giving useful elastic forces, are used in orthodontics field as shaped archs and springs. Their characteristics offer high potentiality to produce new orthodontics devices and to use in implantology. Using different analysis techniques with focussed electron beams, Authors have investigated on the superficial topography, alloy structural composition and on the absorbed elements of superficial layers of Nitinolorthodontics archs. SEM analysis have shown a compact and finished surface. PIXE analysis has quantized the atomic alloy composition in 55% and 45% on nickel and titanium, respectively. Auger spectroscopy and ion sputtering technique have shown that in surface of new archs oxygen and carbon are present up to about 300 A depth.

Med Device Technol 1995 May;6(4):16-20, 22-3
**Using shape-memory alloys.**
Melzer A, Stockel D
Muhlheimer Radiologic Institute, Muhlheim, FRG.

Design considerations and material selection play important roles in the development of surgical instruments for minimally-invasive procedures. Substituting shape-memory or superelastic metals or alloys for conventional materials can lead to a significant improvement in the overall performance of those instruments. In addition, simplicity of design, a reduced number of parts, and ease of assembly and disassembly result in cost reductions.

Biomed Mater Eng 1996;6(6):389-403
**Thermomechanical analysis of shape memory devices.**
Trochu F, Brailovski V, Meunier MA, Terriault P, Qian YY
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Shape memory alloys (SMA) are being increasingly used in various industrial applications as actuators, connectors, or damping materials. In the medical field, superelastic devices such as eyeglass frames, stents or guide catheters have come to market in the recent years. The design of SMA devices has usually been based on trial and error, since until recently no general simulation model was available to assist application engineers. The purpose of this article is to describe the computational methodology developed, validated and used for several industrial projects at Ecole Polytechnique of Montreal to simulate the thermomechanical behavior of shape memory materials. This new approach includes three main stages: experimental characterization, construction of a nonlinear material law based on dual kriging interpolation and finally, calculation of the thermomechanical response of SMA devices. For complex geometry, finite element analysis is used, but for simple devices such as springs or electrically activated SMA wires, simplified calculation methods are satisfactory. Validation results recently obtained will also be presented, and examples of industrial applications briefly reviewed.

Am J Orthod 1980 Feb;77(2):121-32
**Beta titanium: a new orthodontic alloy.**
Burstone CJ, Goldberg AJ

Historically, few alloys have been used in the fabrication of orthodontic appliances. This article reviews the gold-based, stainless steel, chrome-cobalt-nickel, and nitinol alloys, as well as beta titanium, a new material for orthodontics. Mechanical properties and manipulative characteristics are summarized to develop a basis for the selection of the proper alloy for a given clinical situation. The beta titanium wire has a unique balance of low stiffness, high springback, formability, and weldability which indicates its use in a wide range of clinical applications. A number of such applications are described.

Kokubyo Gakkai Zasshi 1991 Mar;58(1):59-73
**[Study of mechanical properties of shape memory alloy plate for internal fixation of jaws].**
[Article in Japanese]
Tomitsuka K
First Department of Oral and Maxillofacial Surgery, Faculty of Dentistry, Tokyo Medical and Dental University.

Ni-Ti alloy compression mini-plate was developed for rigid bone-fixation in oral surgery. The investigation of the mechanical properties of this plate was performed to obtain basic data for its clinical application. Ni-49.49 Ti (at%)alloy and Ni-49.26 Ti (at%) alloy were used for the specimens. First, transformation temperatures of the alloys were measured to evaluate the effect of heat-treatment temperatures. Secondly, tensile and shape recovery tests were performed on four types of mini-plates, i.e., four-hole regular and long types Ni-49.49 Ti (at%), five-hole regular type Ni-49.49 Ti (at%) and Ni-49.26 Ti (at%). The following results were obtained. 1. Specimens with a heat-treatment at 500 degrees C, for 30 minutes in both compositions showed adequate As points (about 25 degrees C) and Af points (44-50 degrees C) for clinical use. 2. In the tensile and shape recovery tests, the 500 degrees C heat-treated four-hole regular type plate showed better mechanical properties than the 440 degrees C heat-treated one. However, in the four-hole regular type plate without heat-treatment, the shape memory effect was rarely found. 3. The five-hole regular type plate of Ni-49.49 Ti (at%) alloy had the best mechanical properties for clinical application, judging from the amount and the temperature of shape recovery. It is concluded that Ni-Ti shape memory alloy mini-plates should be applied for rigid internal bone-fixation in oral surgery.

Iyodenshi To Seitai Kogaku 1983 Apr;21(2):67-72
**[Shape memory alloys and their applications].**
Shimizu K [Article in Japanese]

Iyodenshi To Seitai Kogaku 1985 Feb;23(1):1-6
**[Application of shape memory alloys to the actuator of the artificial heart].**
[Article in Japanese]
Hayashi K, Seki J, Nakamura T

J Osaka Univ Dent Sch 1984 Dec;24:1-12
**Application of Fe-Pd shape memory alloy for dentistry.**
Kimura H, Sohmura T

J Med Eng Technol 1977 Jul;1(4):195-8, 202 contd
**Titanium as a metal for implantation. Part 1: physical properties.**
Williams DF

The scientific basis for the use of titanium and its alloys in implant surgery is reviewed, including the structural metallurgy, mechanical properties, corrosion resistance and biocompatibility. The clinical application are discussed in relation to orthopaedic, oral, plastic and reconstructive and cardiovascular surgery.

J Biomater Appl 1998 Jan;12(3):237-48
**In vitro thermomechanical ageing of Ni-Ti alloys.**
Gil FJ, Planell JA
Dept. Ciencia de los Materiales e Ingenieria Metalurgica, ETSEIB Universidad Politecnica de Cataluna, Barcelona, Spain. gil@cmem.upc.es

NiTi alloy is used as a biomaterial due to its pseudoelastic behaviour. It exhibits a great potential in dental and orthopedic applications where constant correcting loads are required. In order to use such materials, it is necessary to investigate the effect of the cyclic straining upon the transformation stresses and temperatures of the material, the effect of thermal cycling and the ageing at different temperatures and times of heat treatment. The aim of this work is to study the load and thermal cycling and the ageing with the temperature of a superelastic NiTi shape memory alloy.

J Biomed Mater Res 1996 Sep;32(1):77-85
**Initial hemocompatibility studies of titanium and zirconium alloys: prekallikrein activation, fibrinogen adsorption, and their correlation with surface electrochemical properties.**
Yun YH, Turitto VT, Daigle KP, Kovacs P, Davidson JA, Slack SM
Department of Biomedical Engineering, University of Memphis, TN 38152, USA.

Two novel metal alloys, Ti-13Nb-13Zr and Zr-2.5Nb, have been engineered for applications in orthopedic implants because of their favorable mechanical properties, corrosion resistance, and compatibility with bone and tissue. These alloys also have the ability to form a hard, abrasion-resistant, ceramic surface layer upon oxidative heat treatment (diffusion hardening, DH). Previous studies have indicated that these and other ceramics cause limited hemolysis and exhibit remarkable structural integrity after extended exposure to physiological environments. Such observations suggest that DH Ti-13Nb-13Zr and ZrO2/Zr-2.5Nb could be used successfully as components in blood-contacting devices. Materials intended for such applications must possess properties that do not elicit adverse physiological responses, such as the initiation of the coagulation cascade or thrombus formation. In the present study measurements of prekallikrein activation, fibrinogen adsorption from diluted human plasma, and the strength of fibrinogen attachment as judged by residence-time experiments were performed to evaluate the potential hemocompatibility of these materials. The results of the prekallikrein activation and fibrinogen-retention studies correlated well with two electrochemical properties of the alloys, the open circuit potential and reciprocal polarization resistance. The results indicate that both the original and treated Ti and Zr alloys activate prekallikrein and adsorb as well as retain fibrinogen in amounts similar to other materials used as components of blood-contacting devices. On the basis of these studies, these alloys appear to be promising candidates for cardiovascular applications and merit further investigation.

Ann Chir 1994;48(8):731-6
**[Assays of cytotoxicity of the Nickel-Titanium shape memory alloy].**
[Article in French]
Assad M, Lombardi S, Berneche S, Desrosiers EA, Yahia LH, Rivard CH

Centre de Recherche Pediatrique, Hopital Sainte-Justine, Cote Sainte-Catherine, Montreal, Canada.

The equiatomic Nickel-Titanium (NiTi) alloy has exceptional mechanical properties such as shape memory and superelasticity. It already has applications in orthodontics and is a promising orthopaedic biomaterial. Cytocompatibility studies must therefore be undertaken. The objective of this study is to determine the biological response that NiTi elicits compared to other orthopaedic metals currently used in orthopaedic surgery. Cytotoxicity tests constitute an efficient first step in a biocompatibility study and contribute to reduce animal use in laboratory. Direct contact and agar diffusion cytotoxicity assays were performed following ASTM standards #F813-83 and #F895-84 respectively. Confluent L-929 fibroblasts culture plates were incubated (directly or under an agar bed) in presence of NiTi, titanium (Ti), vitallium (Co-Cr-Mo) and 316L stainless steel discs. Following exposition to specimens, a vital dye was added to the plates. All cultures were evaluated for cytotoxic reactions, under light microscopy. Direct contact and agar diffusion assays indicated that all metals tested induced a mild biological reaction. Specimens were ranked according to an index of biological response, they are enumerated here in decreasing order of cytotoxicity: NiTi approximately Co-Cr-Mo >> pure grade 4 Ti approximately pure grade 1 Ti approximately Ti 6A1 4V approximately 316L stainless steel. Furthermore, plasma surface modification increased the cytocompatibility of NiTi.

Rev Orthop Dento Faciale 1988;22(1):31-8
**[Orthodontic use of alloys called "shape memory"].**
[Article in French]
Flageul F

Shika Zairyo Kikai 1984 Jul;3(4):500-7
**[Application of Fe-Pd system shape memory alloys to dentistry. Part 1. On the shape memory effect, corrosion resistance and mechanical properties].**
[Article in Japanese]
Kimura H, Sohmura

Shika Rikogaku Zasshi 1982 Jan;23(61):47-57
**[Studies on new superelastic NiTi orthodontic wire. (Part 1) Tensile and bend test].**
[Article in Japanese]
Watanabe K

NiTi alloy has attracted the most public interest in recent years. This alloy has two unique properties, one is "shape memory effect" and the other is "outstanding elasticity". NiTi wire with the property of outstanding elasticity suggested it could be useful in orthodontics. Recently new NiTi alloy which had other characteristics of "superelasticity" was developed. In this study, new superelastic NiTi wire was examined to evaluate for use in orthodontics, in

tensile and bend tests, compared with stainless steel, Co-Cr alloy and work hardened NiTi wire. The results obtained are as follows: (1) New superelastic NiTi wire showed unique stress-strain curve with a plateau from the strain of 2% to 5%, the unique deformation behavior was caused by stress induced transformation, and returned to almost zero strain as stress was reduced. (2) New superelastic NiTi wire showed an elongation of about 11%. In the cyclic tensile tests to the strain of 8%, new superelastic NiTi wire showed little permanent deformation of 0.5% after 10 cycles. (3) In bend tests, new superelastic NiTi wire showed lower than half load compared with stainless steel and Co-Cr alloy wires. Its permanent deformation was very little after 2 mm deflection. (4) The load-deflection curve of new superelastic NiTi wire showed almost constant load in the wide range of deflection. The results of this study indicate that new superelastic NiTi wire must be considered as a promising candidate for orthodontic arch wire.

Shikai Tenbo 1985 Jun;65(7):1445-54
**[Shape-memory alloys in dentistry].**
[Article in Japanese]
Yoshida T

J Biomater Dent 1987 Sep;3(3):207-15
**[Research on a shape memory NiTi alloy. Orthodontic applications].**
[Article in French]
Bouquet G, Masse M, Missika JM, Portier R

J Biomed Mater Res 1978 Nov;12(6):805-21
**Evaluation of a precipitation hardened wrought cobalt-nickel-chromium-titanium alloy for surgical implants.**
Cahoon JR, Hill LD

A Co-Ni-Cr-Ti precipitation hardening alloy is evaluated for use as a surgical implant alloy. Static and fatigue strength studies indicate that the alloy is equivalent, or superior to, present implant alloys. In vitro and in vivo corrosion studies indicate that the material has good general corrosion resistance but may be susceptible to crevice corrosion. However, there appear to be no inherent difficulties in using precipitation hardened alloys for surgical implants and therefore it may be possible to develop a new class of materials possessing ultra-high strength and excellent corrosion resistance for use in surgical implant applications.

Biomed Mater Eng 1997;7(1):1-11

**Electrochemical and histomorphometric evaluation of the TiNiCu shape memory alloy.**

Wen X, Zhang N, Li X, Cao Z
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msewen@ema.zju.edu.cn

By means of electrochemical and quantitative histomorphometric methods, the corrosion resistance and tissue biocompatibility of Ti50Ni50 and Ti50Ni50-xCux (x = 1, 2, 4, 6, 8) were investigated. It is discovered that the repassivation potential of Ti50Ni50-xCux (x = 2, 4, 6, 8) alloys is about 200 mV higher than that of Ti50Ni50 alloy. Namely, the addition of Cu raises the repassivation potential of TiNi shape memory alloys and improves their corrosion resistance. Pitting potentials of Ti50Ni50 and Ti50Ni50-xCux (x = 1, 2, 4, 6, 8) alloys increase with solution pH value, but the repassivation potentials keep constant. The adding of Cu has no obvious influence on pitting potential (Epit) of TiNi alloys, meanwhile, the corrosion potential and corrosion rate of Ti50Ni50-xCux (x = 1, 2, 4, 6, 8) alloys are irrelevant to its Cu content and the values are almost the same as those of TiNi alloys. The connective tissue layer covering the plates is statistically significantly thicker for Ti50Ni42Cu8 plates ($p < 0.05$) than that of Ti50Ni50, Ti50Ni48Cu2, Ti50Ni44Cu6 plates after one month. The numbers of connective tissue cells, polynucleated cells, macrophages and round cells are higher for Ti50Ni42Cu8 plates than those of the other three types of plates, but no statistically significant differences are detected. There are no significant differences on tissue reaction parameters after two and three months among four alloys. After one, two and three months implantation, no corrosion is observed on the plates surfaces. A preliminary conclusion can be drawn that Ti50Ni50-xCux (x = 2, 6, 8) shape memory alloys have good biocompatibility.

J Biomed Mater Res 1988 Jun;22(6):573-88

**Thermomechanical study of Ni-Ti alloys.**

Lee JH, Park JB, Andreasen GF, Lakes RS
Department of Biomedical Engineering, College of Engineering, Univesity of Iowa, Iowa City 52242.

A preliminary study was conducted to demonstrate the usefulness of the combined technique of differential scanning calorimetry (DSC) and mechanical testing for the shape memory metals of 54NiTi and 53NiTiCo(3%) alloys. The DSC technique was used to measure precise transformation temperatures and the amount of thermal energy required for the corresponding phase transformation. The degree of plastic deformation by bending and the effect of alloying (such as Co) were studied with combined DSC and mechanical property measurements.

Prosthet Orthot Int 1992 Apr;16(1):57-63

**Application of a shape memory alloy to hand splinting.**

Takami M, Fukui K, Saitou S, Sugiyama I, Terayama K
Kakeyu Rehabilitation Research Institute, Nagamo, Japan.

This paper describes new passive splints which have been developed using a shape memory alloy. The peculiar feature of the splints is that the way in which they change shape in use conforms to the stretching motion which it would be desirable to apply in certain conditions of deformity. The alloy consists of 55.66% by weight Nickel and 44.34% Titanium. The heat treatment of the alloy for memorising shape was implemented at 500 degrees C for one hour. This alloy was easily bent when cool, but the original shape was recovered on heating. It was used as the supporting structure of the reverse knuckle bender splint and the cock-up splint. The new splints could be easily attached to the deformed limb after cooling. The splints avoided the development of spasticity, because they gradually recovered their original shapes and corrected the deformities when the heat of the room or body heat warmed the splints. Since the shape memory alloy has the dual function of thermal sensor and kinetic power source it was a simple device. The splint was, as a result, small and smart. It was apparent from clinical use that the splint was easy to wear and could be worn with comfort for an extended period. The design of the splints and the fabrication process are described and their application is indicated.

Med Tekh 1977 Jan-Feb;(1):50-5

**[Use of titanium alloys for medical instruments].**

[Article in Russian]
Feofilov RN, Chirkov VK, Levin MV

On the ground of an analysis into properties of titanium and its alloys the fields of their possible utilization for making various medical instruments are proposed. Because of their insufficient hardness and wear-resistance the titanium alloys cannot be recommended for making medical instruments with thin cutting edges. For the reasons of their insufficient strength, low wear-resistance and substandard modulus of elasticity, it is inexpedient to use titanium alloys in making many types of clamping medical instruments. Nor is it advisable to employ titanium alloys in handles of the instruments, for this may lead to a contact corrosion of their working parts. The use of titanium alloys is recommended for making bone-joining members, retracting medical instruments,of the spatula and speculum types, some kinds of non-magnetic pincers and ultrasonic medical instruments.

Arch Orthop Trauma Surg 1978 Feb 10;91(1):67-75

**[On Dwyer's scoliosis operation using memory alloy wire].**

[Article in German]

Baumgart F, Bensmann G, Haasters J, Nolker A, Schlegel KF

In Dwyer's spinal column correction a titanium cable is stretched from vertebra to vertebra by a special clamp and secured to each vertebra with screws and clips. It is suggested to replace the titanium wire with wire consisting of the memory alloy NiTi. This will permit the prestretched wire to be tensioned by heating it to 60 deg C after it has been fixed at its ends in the vertebrae. The functional principle of the NiTi memory wire was demonstrated in an experiment carried out on a plastic model. This consists of 8 plastic vertebrae with 30 mm sides which are connected by interposed wedge-shaped soft rubber discs, giving the model a curved shape. Memory wire prestretched by 7% is led through eylets on the convex side and fixed at the ends. On being heated (electrically in this experiment for the sake of simplicity), the wire shortens, righting the model so that it assumes a straight shape. The authors also describe in detail the manufacture of the alloy, i.e. the melting and shaping operations, as well as the properties of the material, that is, the stress-strain and strain-temperature relationships and the transformation temperatures, as well as mechanical problems.

Med Prog Technol 1996-97;21(4):187-93

**NiTi shape memory alloys treated by plasma-polymerized tetrafluoroethylene. A physicochemical and electrochemical characterization.**

Yahia LH, Lombardi S, Piron D, Klemberg-Sapieha JE, Wertheimer MR
Biomedical Engineering Institute, Ecole Polytechnique/Faculty of Medicine, University of Montreal, Canada. yahia@grbb.polymtl.ca

NiTi alloy specimens were plasma cleaned and then coated with a thin film of plasma-polymerized tetrafluoroethylene (TFE) in a Radio-Frequency reactor. The corrosion protection provided by these films was studied by potentiodynamic tests performed in Hank's physiological solution. Surface properties which determine biocompatibility were characterized by X-ray photoelectron spectroscopy (XPS). The results showed that the surface of untreated NiTi was mostly composed by oxygen, carbon, titanium oxide (TiO2) with traces of nickel oxides (NiO and Ni2O3) and metallic Ni. The passivity of untreated NiTi was found to be unstable in the simulated human body media. After plasma treatment, the NiTi surface contained only carbon and fluor. The plasma-polymerized thin film was found to stabilize the NiTi passivity and to increase its pitting potential. This treatment provides a good protection against dissolution of nickel from NiTi alloys.

J Thorac Cardiovasc Surg 1994 May;107(5):1255-61

**A new intratracheal stent made from nitinol, an alloy with "shape memory effect".**

Vinograd I, Klin B, Brosh T, Weinberg M, Flomenblit Y, Nevo Z
Department of Pediatric Surgery, Assaf Harofeh Medical Center, Zerifin, Israel.

Temporary or permanent tracheal splinting in pediatric patients may beindicated in tracheomalacia or bronchomalacia, repair of congenital tracheal stenosis, and after tracheal resection. This study presents the results of the development of a new intraluminal airway stent made from titanium alloy, a metal with "shape memory effect". At low temperatures (martensitic state) the titanium alloy stent can be fashioned into a specific shape; then when heated to a higher temperature (austenitic state) the stent alters its shape, only to regain its original shape when recooled to the lower temperature. The stent, connected to a small electric power supply, was introduced into 20 young rabbits with the use of a 2.5 cm rigid bronchoscope. After implantation in themartensitic state the stent was warmed to 40 degrees C, the austenitic state,by an electric current of 1.5 to 3 ampere for 1 to 2 seconds. After a period of 8 to 10 weeks the stent was removed (in its martensitic state) through the same-sized bronchoscope after being cooled with 3 to 4 ml of 80% alcohol solution at 6 degrees C. No signs of airway obstruction developed in any of the animals after implantation or extraction of the stent. The biomechanical properties of the trachea, as shown by strain measurements with the use of incremental forces, showed significant differences between the stented and unstented segments ($p < 0.005$). The titanium alloy intratracheal stent adequately fulfilled the requirements of a temporary intraluminal airway splint, and because of its unique feature of shape memory effect the stent could be inserted, fixed, and removed easily, even in very small airways.

J Biomed Mater Res 1995 Aug;29(8):943-50

**Mechanical properties of the binary titanium-zirconium alloys and their potential for biomedical materials.**

Kobayashi E, Matsumoto S, Doi H, Yoneyama T, Hamanaka H
Institute for Medical and Dental Engineering, Tokyo Medical and Dental University, Japan.

Mechanical properties of titanium-zirconium binary alloys were investigated in order to reveal their possible use for new biomedical materials and to collect useful data for alloy design through a hardness test, a tensile test, and optical microscopy. The hardness of the alloy containing 50% zirconium was approximately 2.5 times as large as the hardness of pure titanium and pure zirconium. Tensile tests showed a similar tendency. No changes between hardness of as cast specimens and as homogenized specimens were observed, nor were changes in microstructures noted. Comparisons between the Ti-6Al-4V alloy and the Ti-Zr-6Al-4V alloy indicated that a titanium-zirconium alloy could provide a base material for a new biomedical alloy. From these results, it was concluded that new alloys for biomedical materials should be designed as titanium-zirconium base alloys.

Am J Orthod Dentofacial Orthop 1986 Jul;90(1):1-10

**The super-elastic property of the Japanese NiTi alloy wire for use in orthodontics.**

Miura F, Mogi M, Ohura Y, Hamanaka H

A new Japanese nickel-titanium (NiTi) alloy wire was developed by the Furukawa Electric Co., Ltd. of Japan. This wire was subjected to uniaxial tensile testing and a specially designed three-point bending test to determine the wire stiffness, and to evaluate spring-back, shape memory, and super-elasticity. The Japanese NiTi wire exhibited an unusual property termed "super-elasticity," which no other orthodontic wire has shown. This phenomenon was researched thoroughly. The wire delivered a constant force over an extended portion of the deactivation range. Among all the wires compared, Japanese NiTi alloy wire was the least likely to undergo permanent deformation during activation. The new alloy exhibited a specific stress-strain curve unlike those of the other tested materials. Stress remained nearly constant despite the strain change within a specific range. This unique feature is the manifestation of so-called super-elasticity. Heat treatment enabled the load magnitude at which super-elasticity is reflected to be influenced and controlled by both temperature and time. A unique and useful process was also developed so that an arch wire delivering various magnitudes of force for a given activation could be fabricated from the wire of the same diameter. The clinical application of wires of this new alloy should be more likely to generate a physiologic tooth movement because of the relatively constant force delivered for a long period of time during the deactivation of the wire. Japanese NiTi alloy should be considered an important material addition to clinical orthodontic metallurgy.

J Biomed Mater Res 1996 Dec;32(4):583-91

**Effect of compressive straining on corrosion resistance of a shape memory Ni-Ti alloy in Ringer's solution.**

Montero-Ocampo C, Lopez H, Salinas Rodriguez A
CINVESTAV-IPN, U. Saltillo, Coah., Mexico.

The effect of various degrees of deformation was investigated at specific locations in the stress-strain curve under compression on the corrosion resistance of a wrought Ni-Ti alloy with a martensite to austenite transformation peak of 110 degrees C. Two metallurgical conditions were evaluated: 30% cold drawn and annealed at 900 degrees C for 1 h. The cold drawn material was tested for corrosion resistance after 5.8, 7.4, 12.2, and 24.5% applied strain. Similarly, the corrosion resistance of the annealed material condition was examined after deformation in compression to 11.9, 22.3, and 24.4% strain. Tafel extrapolation and cyclic polarization tests were used for corrosion characterization of each alloy condition. It was found that the corrosion current density undergoes a significant reduction while the breakdown potential improves at increasing strains. In particular, the alloy in the annealed condition exhibited breakdown potentials above 1000 mV with current densities lower than 10 microA cm-2 when it was strained to 24.4%.

Dtsch Zahnarztl Z 1985 Mar;40(3):254-60
**[Corrosion properties of dental alloys].**
[Article in German]
Weber H

J Biomed Mater Res 1978 Sep;12(5):723-41
**Corrosion behavior of cast and forged cobalt-based alloys for double-alloy joint endoprostheses.**
Sury P, Semlitsch M

An ideal combination of mechanical and corrosion properties of long-term implants such as joint endoprostheses has yet to be found. Besides being resistant to pitting and crevice attack, which can lead to corrosion fatigue and stress corrosion cracking failures, the implant material must be highly resistant to wear and abrasion. Two cobalt-based alloys, wrought CoNiMoTi and air-cast CoCrMo, were subjected to a number of selected in vitro electrochemically and chemically accelerated corrosion tests in chloride-containing solutions with wrought AISI-316L used as a reference alloy. A limited number of immersion tests in FeCl3 and acidified FeCl3 solutions were also conducted. It is found that the mechanical properties of wrought CoNiCrMoTi alloy qualify it as a substitute for cast CoCrMo alloy and wrought AISI-316L in anchorage shaft production for all types of joint endoprostheses. Wrought CoNiCrMoTi has a higher resistance to fatigue cracking compared with cast CoCrMo and is as resistant to selective corrosion phenomena such as stress corrosion cracking.

Biomaterials 1998 Apr-May;19(7-9):761-9
**Electrochemical and surface characterization of a nickel-titanium alloy.**
Wever DJ, Veldhuizen AG, de Vries J, Busscher HJ, Uges DR, van Horn JR
Department of Orthopaedics, University Hospital of Groningen, Netherlands.

For clinical implantation purposes of shape memory metals the nearly equiatomic nickel-titanium (NiTi) alloy is generally used. In this study, the corrosion properties and surface characteristics of this alloy were investigated and compared with two reference controls, AISI 316 LVM stainless steel and Ti6A14V. The anodic polarization curves, performed in Hanks' solution at 37 degrees C, demonstrated a passive behaviour for the NiTi alloy. A more pronounced difference between the corrosion and breakdown potential, i.e. a better resistance to chemical breakdown of passivity was found for the NiTi alloy compared to AISI 316 LVM. X-ray electron spectroscopy (XPS) and scanning electron microscopy (SEM) were undertaken to study the elemental composition and structure of the surface films prior to, and after immersion in Hanks' solution. The passive film on the NiTi alloy consists of a mainly TiO2-based oxide with minimal amounts of nickel in the outermost surface layers. After immersion in Hanks' solution the growth of a calcium-phosphate layer was observed. The passive diffusion of nickel from the NiTi alloy, measured by atomic absorption spectrophotometry reduced significantly in time from aninitial release rate of 14.5 x 10(-7) microg cm(-2) s(-1) to a nickel releasethat could not detect anymore after 10 days. It is suggested that the good corrosion properties of

the NiTi alloy and the related promising biological response, as reported in literature, may be ascribed to the presence of mainly a TiO2-based surface layer and its specific properties, including the formation of a calcium-phosphate layer after exposure to a bioenvironment.

Nippon Rinsho 1988 Oct;46(10):2335-41
**[Applications of the shape memory alloy in clinical medicine].**
[Article in Japanese]
Matsumoto H

Rass Odontotec 1967 Nov-Dec;14(6):35-46 contd
**[The dental alloys].**
[Article in Italian]
Rigatti-Luchini L

Mondo Ortod 1987 Nov-Dec;12(6):67-73
**[NiTi alloys in orthodontics].**
[Article in Italian]
Airoldi G, Visentin C

Rev Odontol Univ Sao Paulo 1989 Jul-Sep;3(3):390-3
**[Mechanical, physical and corrosive properties, and relative cost of a low gold content alloy (46%)].**
[Article in Portugese]
da Silva Filho CE, Muench A
Faculdade de Odontologia da Universidade de Sao Paulo.

The research presents some properties of a low gold content (46%) alloy. Mechanical properties were performed with specimens submitted to several treatment; as cast; hardened at 400 degrees C/15 min; softened at 700 degrees C/10 min; and hardened after softening. Melting temperature was considered when the alloy become a liquid sphere. Casting shrinkage determination was based on the method presented by EARNSHAW. Density was obtained by the weight of polished specimens in and out of water. Corrosion was tested at vapors of acetic acid solution, saturated with hydrogen sulfide, for a period of six months. Cost was computed on base of materials cost and density of alloy. The results showed: tensile strength and proportional limit are very high,specially when hardened and the alloy may be used for large bridges; elongation is low when alloy was heat hardened, but is good when in the as cast condition; the alloy may be handled with conventional materials and equipment; corrosion resistance is excellent; final cost is a little higher than half that of conventional gold alloy.

Eur J Orthod 1991 Jun;13(3):179-86

**Potential application of shape memory plastic as elastic material in clinical orthodontics.**

Nakasima A, Hu JR, Ichinose M, Shimada H
Department of Orthodontics, Kyushu University, Japan.

Polynorbornen, a shape memory plastic developed in Japan, has a glass transitional point of 35 degrees C. Once the environmental temperature exceeds the critical point, this plastic will begin to display an elastic property, then return to its original shape, if deformed. We examined whether the force generated during the elastic phase of polynorbornen could be used to displace human teeth. We found that the shape memory plastic wire of 1 mm in diameter stretched to two to three times of its original length at a temperature of 50 degrees C and a speed of 0.5 mm/sec would exert a relatively stable continuous light force of 119-156 g to move the teeth. This new material, compared with conventional elastic modules used in orthodontic therapy, exhibited a lesser degree of force degradation at a body temperature of 37 degrees C for a long period, and can be manufactured to near the tooth colour required. These advantages make feasible clinical application of the shape memory plastic in orthodontics.

Shika Rikogaku Zasshi 1978 Jan;19(45):8-14

**[Studies on dental casting ferromagnetic alloys].**

[Article in Japanese]

Sasaki H, Yoshida Y, Kinouchi Y, Miyazaki T

We previously reported successful applications of rare earth-cobalt magnets to dental prostheses. In order to use magnets more effectively, ferromagnetic materials with a high magnetic permeability and a high saturation flux density should be used as prosthetic materials. This type of material will form a good magnetic path, and consequently tighten the magnetic attracting force by preventing the magnetic flux from leaking into the mouth tissue. A few alloys were newly prepared by using Pd, Co and Cr, the usual dental metals, and tested. It was found that: (1) These alloys have suitable magnetic properties. (2) The corrosion resistances of the Pd-Co and Pd-Co-Cr alloys are as good as those of dental casting Ag and Ni-Cr alloys, respectively. (3) The physical and mechanical constants of the alloys are similar to those of the usual dental casting alloys. (4) These alloys can be used as dental casting ferromagnetic alloys. (5) The Pd-Co alloy can also be used as a porcelain bonding alloy.

Dtsch Zahnarztl Z 1979 Nov;34(11):830-2
**[Damage from galvanic corrosion of dental alloys].**
[Article in German]
Zitter H, Pitner P

Failure analysis reveals, that using different materials for expansion screws and fixing elements may cause severe galvanic corrosion or pitting corrosion. Such failures can easily be avoided by using only one alloy with good passivation characteristics instead of different alloys.

Chung Hua Wai Ko Tsa Chih 1993 May;31(5):259
**[Prospects for the clinical uses of shape-memory nitinol alloy in surgery].**
[Article in Chinese]
Lu SB
Editorial

Biomaterials 1995 Feb;16(3):239-44
**Development of a titanium alloy suitable for an optimized coating with hydroxyapatite.**
Breme J, Zhou Y, Groh L
Lehrstuhl Metallische Werkstoffe, Universitat des Saarlandes, Saarbrucken, Germany.

By means of the metallurgical method of alloying, the thermal expansion coefficient of commercially pure titanium was adapted to that of hydroxyapatite (HA) in order to produce a tailored composite material with a maximum adhesion strength of HA to the metallic material. The alloying element chosen was manganese, which is an important trace element in the human organism. With the alloy TiMn6 a good compromise concerning the expansion coefficient, the mechanical properties and the biocompatible behaviour was found. With this alloy coatings with an extremely high adhesion strength could be produced, especially when the sol-gel process was used for HA precipitation. In addition, these layers fulfil the requirements of favourable thin coatings according to theoretical considerations.

Chung Hua Wai Ko Tsa Chih 1993 May;31(5):272-4
**[Shape memory alloy spiral for urethrostenosis caused by benign prostatic hyperplasia].**
[Article in Chinese]
Qiu CY
251 Hospital, People's Liberation Army, Zhangjiakou.

The nitinol (shape memory alloy, SMA) spiral was used in 39 patients with benign prostatic hyperplasia (BPH). Caine experiment indicated that the spiral could be embedded by prostatic urethra epithelium in 6 months. The new transitional epithelium between spiral wires was originated from the urethra transitional epithelium as proved by immunohistochemical staining. The parts of spiral project over the bladder cavity formed incrustation on the spiral tip. The nitinol is of super-elastic property, corrosive-resistance and excellent biocompatibility, in addition to unique shape memory effect. We treated 39 patients with BPH by self-made coaxial sheath introducing Chinese nitinol spiral into the prostatic urethra, with a successful rate of 89.7%. Follow-up for 3-26 months showed no incrustation and migration of the spiral.

Czas Stomatol 1970 Feb;23(2):83-91
**[Studies on the possibility of application of Stabil-B silver alloy of Polish production as a material for inlays].**
[Article in Polish]
Mikosza H, Mitrega J, Turostowski F, Wojtuszkiewicz J

Dent Labor (Munch) 1990 Jul;38(7):933-6
**[Corrosion and biocompatibility of dental alloys].**
[Article in German]

Dent Mater 1990 Oct;6(4):228-36

**Dynamic mechanical properties of straight titanium alloy arch wires.**

Kusy RP, Wilson TW
Dental Research Center and Biomedical Engineering, University of North Carolina, Chapel Hill.

Eight straight-wire materials were studied: an orthodontic titanium-molybdenum (Ti-Mo) product, TMA; three orthodontic nickel-titanium (Ni-Ti) products, Nitinol, Titanal, and Orthonol; three prototype alloys, a martensitic, an austenitic, and a biphasic alloy; and a hybrid shape-memory-effect product, Biometal. Each wire was prepared with a length-to-cross-sectional area of at least 3600 cm-1. With an Autovibron Model DDV-II-C used in the tensile mode, each sample was scanned from -120 to +200 degrees C at 2 degrees C/min. From the data base, plots of the log storage modulus, log tan delta, and percent change in length vs. temperature were generated. Results showed that the dynamic mechanical properties of the alloys within this Ti system are quite different. The Ti-Mo alloy, TMA, was invariant with temperature, having a modulus of 7.30 x 10(11) dyne/cm2 (10.6 x 10(6) psi). The three cold-worked alloys--Nitinol, Titanal, and Orthonol--appeared to be similar, having a modulus of 5.74 x 10(11) dyne/cm2 (8.32 x 10(6) psi). The biphasic shape-memory alloy displayed a phase transformation near ambient temperature; whereas the hybrid shape-memory product, Biometal, underwent a 3-5% change in length during its transformation between 95 and 125 degrees C. Among the Ni-Ti wires tested, several different types of alloys were represented by this intermetallic material.

Shika Rikogaku Zasshi 1979 Jan;20(49):40-3

**[Study of gold-nickel alloy. (Part 1) The properties of gold-nickel binary alloys].**

[Article in Japanese]

Hirano S, Hirasawa T

To research the possibility of a new dental Au base alloy, Au-Ni alloys were examined. Comospitions were 82.5% Au-17.5% Ni alloy, 77% Au-23% Ni alloy and 70% Au-30% Ni alloy. Mechanical properties of these alloys were equal to those of hardened Au added Pt alloy or type IV Au alloy. And these alloys have shown no tarnish and corrosion in 0.1% NaS solution, 0.05% HC1 solution or 1% Lactic acid solution after 21 days. Especially 77% Au-23% Ni alloy was the best among them.

J Biomed Mater Res 1999;48(2):165-71

**Preliminary investigation of the effects of surface treatments on biological response to shape memory NiTi stents.**

Trepanier C, Leung TK, Tabrizian M, Yahia LH, Bienvenu JG, Tanguay JF, Piron DL, Bilodeau L
Biomechanics/Biomaterials Research Group, Biomedical Engineering Institute, Ecole Polytechnique of Montreal, Canada.

Nickel-titanium (NiTi) offers many advantages for the fabrication of coronary stents: shape memory, superelasticity, and radiopacity. However, many authors highlighted the selective dissolution of Ni from the alloy during the corrosion process that could lead to potential toxicity. The improvement of the NiTi stent's corrosion resistance by different surface treatments (electropolishing, heat treatment, and nitric acid passivation) was reported in a previous article. In the present study a comparative biocompatibility evaluation of such stents was performed through in vitro and in vivo assays. A cell proliferation test was completed to evaluate the cytotoxicity of surface treated NiTi using human fibroblasts. Then a stent implantation was performed in rabbit paramuscular muscle to study the inflammatory response generated by the same implants. Cell proliferation tests generally indicated an in vitro biocompatibility of our samples similar to the control group. An in vivo implantation study demonstrated the gradual overall reduction with time of the fibrocellular capsule thickness surrounding the implants. After a 12-week implantation period, the fibrous capsules surrounding the different implants tended toward the same value of 0.07 mm, which suggested that all surface treatments produced a similar biological response. This low value of the fibrocellular capsule indicated that our NiTi surface treated implants were relatively inert.

Minerva Stomatol 1997 Jul-Aug;46(7-8):381-9

**[Experience with a rigid fixation device in maxillofacial surgery using shape-memory clips].**

[Article in Italian]

Itro A, Garau V, Tartaro GP, Colella G
Facolta di Medicina e Chirurgia, II Universita degli Studi, Napoli.

BACKGROUND: A device of alloy with shape-memorising effect (SME) was utilized in the surgical correction of maxillo-facial fractures. Nitinol, an alloy of equal atomic parts nickel and titanium, is a metal with the unusual property of shape memory. This alloy may be easily bent when cooled in its lower temperature phase and it resumes its original shape when heated in its higher temperature phase. A lot of useful properties of nitinol alloy, such the ability to convert heat energy into mechanical energy, as the biocompatibility
and bioinertness, as the anti corrosive stability and high mechanical strength, suggest that it can be useful in the surgical fixation of maxillofacial bone injuries. METHODS: The fixing device of alloy with SME, the indications and the techniques of osteosynthesis and some cases have been discussed by the authors. RESULTS AND CONCLUSIONS: The results of this study showed that the surgical treatment of maxillo-facial bone fractures by devices of shape memory alloys is simple, ensures a good stability of

fracture surfaces, reduces the time period of operative procedures and of patients rehabilitation, allowing rapid bone healing.

Int Dent J 1993 Jun;43(3):245-53
**Titanium and titanium alloys as dental materials.**
Lautenschlager EP, Monaghan P
Northwestern University Dental School, Chicago, Illinois 60611-2909.

Because of light weight, high strength to weight ratio, low modulus of elasticity, and excellent corrosion resistance, titanium and some of its alloys have been important materials for the aerospace industry since the 1950s. Now, with the additional advantages of excellent biocompatibility, good local spot weldability, and easy shaping and finishing by a number of mechanical and electrochemical processes, these materials are finding uses in dental applications, such as implants and restorative castings. Although more research is still needed in areas such as development of optimal casting investments, porcelain veneering systems, device designs, and controlled biological responses, the present and future uses of titanium appear bright for dentistry.

Biomed Sci Instrum 1993;29:47-50
**Biomedical uses of shape memory polymers.**
Frenger P
A Working Hypothesis, Inc., Houston, TX 77282-0506.

A new type of plastic polymeric material is described which can dramatically change its physical properties with temperature. These changes include hardness, flexibility, modulus of elasticity and shape. These changes occur within a very narrowly defined range of temperatures, which can be controlled in the manufacturing process. These "memory resins" can be formed by casting, extruding, injection molding and solution coating into a rigid form which has low cytotoxicity. Warming followed by cooling allows forming of the material; the new shape is retained until the part is rewarmed and recooled, at which time the part reverts to its original manufactured shape. The author describes several current and proposed uses for these shape memory polymers.

J Biomed Mater Res 1984 Apr;18(4):427-34
**Casting properties of Ni-Ti shape memory alloy.**
Takahashi J, Okazaki M, Kimura H, Furuta Y

A Ni-45 wt% Ti (Ni-50 at % Ti) alloy was cast into molds of magnesia and silica investments by use of a dental argon-arc pressure casting machine with a copper crucible . The castings exhibited shape memory properties. The shape recovery process was sharper in the specimens cast in magnesia investment molds than in those cast in silica (phosphate-bonded) investment molds. The latter casting had a hard region of the periphery, suggesting that shape recovery process may be affected by reaction of molten metal with silica. Furthermore, the alloy possessed the adequate mechanical properties for consideration as crown-and-bridge prostheses.

Rev Bras Odontol 1968 Jan-Feb;25(149):9-13
**[Some properties of commercial amalgam alloys in S. Paulo].**
[Article in Portugese]
Muench A

Am J Orthod Dentofacial Orthop 1988 Aug;94(2):89-96
**The super-elastic Japanese NiTi alloy wire for use in orthodontics. Part III. Studies on the Japanese NiTi alloy coil springs.**
Miura F, Mogi M, Ohura Y, Karibe M
1st Department of Orthodontics, School of Dentistry, Tokyo Medical and Dental University.

Closed and open Japanese nickel titanium (NiTi) alloy coil springs were fabricated from the Japanese NiTi alloy wire. The closed coil springs were subjected to a tensile test and the open coil springs were subjected to a compression test to evaluate the mechanical properties. At the same time, a test with the commercially available steel coil springs also was done. It was clearly established that the Japanese NiTi alloy coil springs exhibited superior springback and super-elastic properties similar to the properties of the Japanese NiTi alloy arch wires. In addition, it was shown that the load value of super-elastic activity can be effectively controlled by changing the diameter of the wire, the size of lumen, the martensite transformation temperature, and the pitch of the open coil spring. The most important characteristic of the Japanese NiTi alloy coil springs is the ability to exert a very long range of constant light, continuous force. It is possible to use this coil selectively to obtain optimal tooth movement.

Mondo Ortod 1989 Jan-Feb;14(1):79-83
**[Use of titanium alloys in orthodontics].**
[Article in Italian]
Curro G, De Luca FP
**The Authors review the story of orthodontic alloys and show some clinical application of new titanium alloys.**

Stomatol Glas Srb 1989 Jan-Feb;36(1):33-40
**[Application of low noble alloys in telescoped crowns].**
[Article in Serbo-Croatian (Roman)]
Susulic T

It is known that low noble alloys (Hera SG, Aurea-Heraus, Stabilor-Degussa, Midgold-Bego etc.) are used woredwide for the preparation of prosthetic constructions. For this reason attempts to produce low noble alloys with the properties equal to those of more expensive high noble alloys, are justified, as they are cheap and available to a great number of patients. The Yugoslav producer of dental materials "Zlatarna Celje" has produced a low noble alloy named Midor S. The comparative investigations of resistance to the mouth, performed at the University School of Dentistry in Ljubljana and in the Laboratory of Metallurgy of "Zlatarna Celje", have shown that this alloy was more

resistant to corrosion than 22 karat, high noble alloy. In our Department Mikdor S was experimentally tested on telescoped crowns. The obtained results showed the satisfactory hardness and resistance to attrition between the internal and external crowns within the limits of tolerance which made it suitable for use.

J Biomed Mater Res 1975 Jul;9(4):133-48
**The use of dissimilar metals in surgery.**
Mears DC

Previously, the use of dissimilar metals for the construction of surgical implants has been strongly discouraged because the combination of metals was likely to provoke more rapid corrosion of one metal. With the passive alloys that are in present and future application, however, a reconsideration of the use of dissimilar metals is required. Presently available electrochemical tests allow accurate prediction of safe and unsafe combinations of metals. The use of dissimilar metals would permit selection of the alloy of appropriate mechanical properties for each part of an implant and would allow improved corrosion resistance that certain alloys can convey to other alloys with which they are in contact.

Ann Biol Clin (Paris) 1998 Mar-Apr;56(2):132
**Out of memory.**
Dhondt JL
Hopital Saint-Philibert, Lomme.

BMJ 1998 May 30;316(7145):1681
**What kind of memory?**
Farrell L
general practitioner, Crossmaglen.
[Medline record in process]

Nippon Seikeigeka Gakkai Zasshi 1993 Apr;67(4):267-74
**Correction of scoliosis with shape-memory alloy.**
Matsumoto K, Tajima N, Kuwahara S
Department of Orthopedic Surgery, Miyazaki Medical College, Japan.

Using NiTi shape-memory alloy, we devised an instrument for correction of scoliosis. Our instrument is characterized by gradual correction of the spine. Restoration power of the alloy was 25 kgcm in a rod with a diameter of 3 mm, 45 kgcm in a 4-mm rod, and 110 kgcm in a 5-mm rod. Spinal cord injuries on heating the rod were observed at an epidural temperature of 48 degrees C or more, suggesting that 48 degrees C is the critical temperature. The blood Ni concentration after implantation of the NiTi alloy rod reached a level twice normal after 6-9 hours. After 4 weeks, the Ni concentration increased 4-fold in the kidneys, 2-fold in the liver, and 10-fold in the urine. Alloy rods were attached to a scoliosis monkey and heated gradually. Scoliosis with a Cobb angle of 43 degrees was completely corrected.

J Urol 1995 Sep;154(3):1065-8
**Placement of the urethral stent made of shape memory alloy in management of benign prostatic hypertrophy for debilitated patients.**
Mori K, Okamoto S, Akimoto M
Division of Urology, St. Luke's Hospital, Tokyo, Japan.

PURPOSE: A new urethral stent made of shape memory alloy was placed to relieve prostatic obstruction in 17 patients in whom other approaches were contraindicated. MATERIALS AND METHODS: All patients were unable to tolerate intervention with sedation and positioning. Placement of the shape memory alloy stent mounted on a 16F Foley catheter is similar to insertion of a urethral catheter except for the heat-sensitive expansion. RESULTS: Each device was easily implanted with the patient on a flat examination table. There was no migration or incrustation of the shape memory alloy stent during the indwelling period. CONCLUSIONS: Clinical results demonstrate that the shape memory alloy urethral stent might be the only choice for management of prostatic obstruction in debilitated patients.
Clinical trial

Boll Metallogr 1971 Jun;25(6):451-4 contd
**[Dental alloys. Alloy wires].**
[Article in Italian]

J Can Dent Assoc 1969 Jan;35(1):35-9
**Strength properties of a conventional and a spherical particulate amalgam alloy.**
Roydhouse RH

Chung Hua Wai Ko Tsa Chih 1986 Mar;24(3):129-32, 187
**[Treatment of scoliosis with a shape-memory alloy rod].**
[Article in Chinese]
Lu SB, Wang JF, Guo JF

Biomater Med Devices Artif Organs 1979;7(1):155-67
**Fatigue - corrosion of endoprosthesis titanium alloys.**
Cornet A, Muster D, Jaeger JH

Commercial total hip prostheses often show certain metallurgical faults (porosities, coarse grains, growth dendrites, carbide networks). In order to investigate more accurately the role played by these different parameters in prostheses failure we performed a large number of systematic corrosion, fatigue and fatigue - corrosion tests on these materials and on commercial total hip prostheses. Ultimate strengthes seem to be reached for cast cobalt alloys, whereas titanium alloys, such as Ta 6 V, present very high fatigue limit under corrosion. Thus, rotative bending fatigue - corrosion tests in biological environment provide values about 50 DaN/mm2. This value, is nevertheless appreciably higher than those obtained with stellites and stainless steel. Titanium alloys,

because of their mechanical performances, their weak Young's modulus (11000 DaN/mm2) and their relative lightness (4.5. g/cm3), which are associated with a good biocompatibility, seem very promising for permanent implants realisation.

Biomaterials 1998 Jul;19(13):1197-215

**Corrosion resistance, mechanical properties, corrosion fatigue strength and cytocompatibility of new Ti alloys without Al and V.**

Okazaki Y, Rao S, Ito Y, Tateishi T

Mechanical Engineering Laboratory, Agency of Industrial Science and Technology, Ministry of International Trade and Industry, Ibaraki, Japan. m4610@mel.go.jp

The effects of various metallic ions using various metallic powders on the relative growth ratio of fibroblasts L929 and osteoblasts MC3T3-E1 cells were carried out. Ti, Zr, Sn, Nb and Ta had evidently no effect on the relative growth ratios of cells. Otherwise, Al and V ions exhibit cytotoxicity from a concentration of > or = 0.2 ppm. This Al effect on cells tend to be stronger in medium containing small quantity of V ions (< or = 0.03 ppm). The new Ti-15%Zr-4%Nb-4%Ta-0.2%Pd alloy exhibited a higher corrosion resistance in physiological saline solution. The addition of 0.02%O and 0.05%N to Ti-Zr alloy improved the mechanical properties at room temperature and corrosion fatigue strength. The relative growth ratios for the new Ti alloy plate and the alloy block extraction were unity. Further, the relative growth ratios were almost unity for the new Ti alloy against apatite ceramic pins up to 10(5) wear cycles in Eagle's MEM solution. However, there was a sharp decrease for Ti-6%Al-4%V ELI alloy from 3 x 10(4) wear cycles as V ion was released during wear into the wear test solution since the pH of the Eagle's MEM increases with increasing wear cycles.

Spine 1993 Sep 15;18(12):1640-6

**A preliminary investigation of shape memory alloys in the surgical correction of scoliosis.**

Sanders JO, Sanders AE, More R, Ashman RB

Department of Orthopaedics, University of Texas Health Science Center at San Antonio.

Nitinol, a shape memory alloy, is flexible at low temperatures but retains its original shape when heated. This offers interesting possibilities for scoliosis correction. Of the shape memory alloys, nitinol is the most promising medically because of biocompatibility and the ability to control transition temperature. In vivo: Six goats with experimental scoliosis were instrumented with 6-mm nitinol rods. The rods were transformed, and the scoliosis corrected, in the awakened goats by 450-kHz radio frequency induction heating. The curves averaged 41 degrees before instrumentation, 33 degrees after instrumentation, and 11 degrees after rod transformation. The animals tolerated the heating without discomfort, neurologic injury, or evidence of thermal injury to the tissues or the spinal cord. In vitro: Nitinol rods were tested under both constant deflection and constant loading conditions and plotted temperature versus either force or displacement. The 6-mm rod generated forces of 200 N. The 9-mm rod generated up to 500 N. We safely coupled shape memory alloy transformation to the spine and corrected an experimental spinal deformity in awake animals. The forces generated can be estimated

by the rod's curvature and temperature. The use of shape memory alloys allows continuous neurologic monitoring during awake correction, true rotational correction by rod torsion, and the potential option of periodic correction to take advantage of spinal viscoelasticity and the potential of true rotational correction by rod torsion.

Int Dent J 1983 Mar;33(1):41-8
**The physical properties of some alternative alloys.**
Johnson LN

Over the past 30 years the 'traditional' gold alloy systems have been modified by reducing the percentage of gold and other noble metals to the point where the 'non-precious metal' alloys have no noble metal content. These include the nickel-based alloys, cobalt-based alloys and certain experimental alloys, all suitable for porcelain application. This application demands castability, compatibility with investments, suitable finishing properties, appropriate thermal expansion, chemical bonding with porcelain, solderability and biocompatibility. Recent research into these functional requirements has (1) confirmed the role of Cr in corrosion resistance; (2) related high fusion tempera tures to surface roughness and inaccurate fit; (3) demonstrated the importance of casting size and thickness; (4) related castability to the choice of investment for a particular alloy; (5) provided a method for controlling the deposition of oxide film upon the casting; and (6) shown that the re-use of base metal alloy has an adverse effect upon the mechanical properties of the casting. The expense of manipulating the base metal alloys to some extent offsets their cost-benefit advantage over traditional gold alloys. It is possible that Cr will not remain freely available, in which case its price too will soar.

Kokubyo Gakkai Zasshi 1966 Mar;33(1):1-4
**[On the composite alloys].**
[Article in Japanese]
Miura K

Int J Oral Maxillofac Implants 1989 Summer;4(2):113-8
**Comparison of titanium-tantalum and titanium-niobium alloys for application as dental implants.**
Breme J, Wadewitz V

For the diffusion bonding of Ti alloys to alumina, materials with a similar thermal expansion coefficient to alumina are required. Such materials were developed by alloying the biocompatible elements Ta and Nb to titanium (Ti-Ta30 and Ti-Ta40, Ti-Nb40 and Ti-Nb50). While measuring the corrosion behavior of these alloys in 0.9% saline solution, no difference could be observed. The Ti-Ta alloys are superior in their mechanical properties to Ti-Nb alloys.

Radiology 1977 Oct;125(1):87-94
**A vena cava filter using thermal shape memory alloy. Experimental aspects.**
Simon M, Kaplow R, Salzman E, Freiman D

Surgical ligation of the vena cava in the treatment of pulmonary embolism is already being superseded by devices introduced via a peripheral vein. A new metal alloy (nitinol) with unique memory characteristics forms the basis of an experimental device which promises even greater safety, simplicity and speed of introduction. It is inserted as a straight thin wire via the small bore catheter used for angiographic diagnosis. Upon reaching the lumen of the inferior vena cava and sensing body temperature, it reverts to its preset complex filter shape and locks into place permanently. It will trap further thromboemboli from the pelvis or lower limbs.

Stomatologiia (Mosk) 1996;75(3):10-4

**[The corrosion and electrochemical properties of new palladium-indium alloys for dentistry].**

[Article in Russian]

Maksimovskii IuM, Grinin VM, Kortukov EV, Gorbov SI, Karagodin IuA, Sinitsyn AA

New palladium-based dental materials were examined in a wide spectrum of pH values from 3.8 to 9.6 at 37 degrees C for 315 h. Palladium dissolves in acid (pH 3.8) media with subsequent passivation (formation of complex compounds); areas of passiveness of palladium and its alloys for other pH values were found. The potentials of passiveness currents emerging in such cases were defined for all media, and corrosion curves of the alloys plotted. A film of palladium oxide appearing on the surface of the alloy was found to prevent further corrosion. High corrosion resistance in artificial saliva and high chemical inertness of palladium-indium alloy was revealed. The mechanisms of selective corrosion of the examined alloys and passiveness currents are discussed from the viewpoint of modern physical chemistry, and experimental data are explained. Use of such alloys in dentistry is shown to hold good promise.

Biomed Mater Eng 1996;6(4):241-54

**Corrosion resistance improvement of NiTi osteosynthesis staples by plasma polymerized tetrafluoroethylene coating.**

Villermaux F, Tabrizian M, Yahia L, Czeremuszkin G, Piron DL
Biomedical Engineering Institute, Biomechanics/Biomaterials Research Group,
Ecole Polytechnique de Montreal, Quebec, Canada.

NiTi shape Memory Alloys (SMA) are potential biomaterial candidates for medical devices such as osteosynthesis staples. However, Ni dissolution induced by uniform or localized corrosion could lead to toxicity. In this work, plasma polymerized tetrafluoroethylene (PPFTE) coating is used to improve the corrosion resistance of NiTi plates and corresponding NiTi stables. The scratch test indicates a good surface adhesion of the film but that it lacks cohesiveness. Potentiodynamic tests in physiological Hank's solution show that PPTFE coating improved the pitting corrosion resistance. The passivation range is increased from 35% to 96% compared to the untreated sample and the pit diameter is decreased from 100 microns to 10 microns. The uniformity of the deposited film is a very important parameter. When the film is damaged, the corrosion seems to increase in comparison to the untreated samples. Otherwise, if the staple is carefully manipulated, the coating follows the large

deformations induced by the memory effect of the alloy without cracking, and then, protects efficiently the staple from pitting.

Biol Bull 1996 Aug;191(1):139-43
**Flies, genes, and memory engineering.**
Gelperin A
Bell Laboratories, Lucent Technologies, Murray Hill, New Jersey 07974, USA.

Shika Zairyo Kikai 1984 Nov;3(6):821-5
**[Application of Fe-Pd system shape memory alloys to dentistry (2). On the anodic polarization behavior and biological reaction].**
[Article in Japanese]
Kimura H, Sohmura T

J Prosthet Dent 1971 Jun;25(6):650-6
**Clinical evaluation of corrosion resistance of conventional alloy, spherical-particle alloy, and dispersion-phase alloy.**
Duperon DF, Nevile MD, Kasloff Z

Rass Odontotec 1968 Sep-Oct;15(5):34-48 contd
**[The dental alloys].**
[Article in Italian]
Rigatti Luchini L

J Biomed Mater Res 1988 Jul;22(7):649-66
**Corrosion behavior of nickel-containing alloys in artificial sweat.**
Randin JP
ASULAB S.A., Research Laboratories of the SMH Group, Neuchatel, Switzerland.

The corrosion resistance of various nickel-containing alloys was measured in artificial sweat (perspiration) using the Tafel extrapolation method. It was found that Ni, CuNi 25 (coin alloy), NiAl (colored intermetallic compounds), WC + Ni (hard metal), white gold (jewelry alloy), FN42 and Nilo Alby K (controlled expansion alloys), and NiP (electroless nickel coating) are in an active state and dissolve readily in oxygenated artificial sweat. By contrast, austenitic stainless steels, TiC + Mo2C + Ni (hard metal), NiTi (shape-memory alloy), Hastelloy X (superalloy), Phydur (precipitation hardening alloy), PdNi and SnNi (nickel-containing coatings) are in a passive state but may pit under certain conditions. Cobalt, Cr, Ti, and some of their alloys were also investigated for the purpose of comparison. Cobalt and its alloys have poor corrosion resistance except for Stellite 20. Chromium and high-chromium ferritic stainless steels have a high pitting potential but the latter are susceptible to crevice corrosion. Ti has a pitting potential greater than 3 V. Comparison between the in vitro measurements of the corrosion rate of nickel-based alloys and the clinical observation of the occurrence of contact dermatitis is discussed.
Rofo Fortschr Geb Rontgenstr Neuen Bildgeb Verfahr 1990 Jun;152(6):698-701

**[Perorally insertable endotracheal stents made from NiTi memory alloy--an experimental animal study].** [Article in German]
Rauber K, Franke C, Rau WS, Syed Ali S, Bensmann G
Zentrum der Radiologie, Justus-Liebig-Universitat, Giessen.

NiTi prostheses were perorally inserted in 12 rabbits. The spiral prostheses were overgrown by normal tracheal epithelium over time. No adverse effects due to impairment of the mucociliary clearance and no chondromalacia occurred. We conclude that perorally insertable prostheses made of the shape-memory alloy NiTi may be used as endotracheal or endobronchial prostheses.

Ankara Univ Hekim Fak Derg 1990 Jan;17(1):145-50
**[Non-precious alloys for ceramo-metal restorations].**
[Article in Turkish]
Avci M

Rapidly increasing gold prices hastened the widespread use of non-precious alloys for ceramo-metal restorations. Especially base-metal alloys has been considerably improved and has shown much progress after a long period of study and use. Among these alloys, nickel-chromium and cobalt-chromium alloys are quite popular in our country, like in Europe and in U.S.A. Their physical properties are superior than noble-metal alloys which are used for ceramo-metal restorations. However, some questions arise in the dental literature about their corrosion resistance, biocompatibility and porcelain bonding properties. This article reviews the constituents, physical properties, porcelain bonding, biocompatibility and corrosion resistance of nickel-chromium and cobalt-chromium alloys.

Hiroshima Daigaku Shigaku Zasshi 1981 Dec;13(2):362-3
**[Application of a new TiNi gold alloy: the shape memory effect and thermoelasticity].**
[Article in Japanese]
Wakase K, Yamamoto M

Chung Hua Wai Ko Tsa Chih 1983 Jun;21(6):343-5
**[Orthopedic application of a Ni-Ti shape-memory alloy compression staple].**
[Article in Chinese]
Dai KR